POWER SAVINGS APPARATUS AND METHOD FOR WIRELESS NETWORK DEVICES

FIELD OF THE INVENTION

[0001] The present invention relates to networks, and more particularly to reducing power consumption of wireless network devices.

BACKGROUND OF THE INVENTION

[0002] IEEE section 802.11, which is hereby incorporated by reference in its entirety, defines several different standards for configuring wireless Ethernet networks and devices. For example, 802.11 standards that have been popularized include 802.11(a), 802.11(b) and 802.11(g). Wireless Ethernet network devices may be implemented by a system on chip (SOC) circuit that includes a baseband processor (BBP), a medium access controller (MAC) device, a host interface, and one or more processors. The SOC circuit may include a radio frequency (RF) transceiver or the RF transceiver may be located externally. The host interface may include a peripheral component interface (PCI) although other types of interfaces may be used. The processor(s) may be advanced RISC machine (ARM) processor(s), although other types of processors may be used.

[0003] The MAC device controls and selects different operating modes of the BBP and the RF transceiver. During operation, the MAC device instructs the BBP and the RF transceiver to transition to a low power mode to conserve power. The BBP and RF transceivers may include phase-locked loops (PLL).

The PLLs are calibrated using a reference signal that is supplied by a crystal oscillator (XOSC). [0]The SOC may also include voltage regulators that provide regulated supply voltages to the system.

[0004] The Ethernet network device is usually associated with a host system ("host"). In an infrastructure mode, the host communicates with a network via the Ethernet network device and an access point (AP). The MAC device typically instructs the BBP and the RF transceiver to transition to the low power mode when the AP and the host do not have data to exchange. However, the voltage regulator in the BBP remains active during the low power mode and still consumes a significant amount of power. Additionally, the XOSC and PLL devices remain active and also consume power during the low power mode.

[0005] In some conventional approaches, the operating voltage and/or the clock frequency are reduced during the low power mode while still allowing the system to operate at full capacity. However, many system components remain active during the low power mode and continue to consume power. In other conventional approaches, the way that functions are implemented is modified to reduce power consumption. For example, the device may lower a frequency of operation so that calculations take longer to complete. However, these system components still continue to consume power even when there are no computations to be performed.

SUMMARY OF THE INVENTION

[0006] A wireless Ethernet network device according to the present invention has active and low power modes. A first voltage regulator regulates supply voltage during the active mode. A second voltage regulator dissipates less power than the first voltage regulator and regulates supply voltage during the low power mode. A medium access controller (MAC) device selects the first voltage regulator during the active mode and the second voltage regulator during the low power mode.

[0007] In other features, a baseband processor (BBP) communicates with the MAC device. At least one of the first and second voltage regulators is located in the BBP. A first phase locked loop (PLL) generates a clock signal for the BBP during the active mode. The first PLL is located in the BBP.

[0008] In still other features, a crystal oscillator outputs a timing signal to the first PLL during the active mode. A radio frequency (RF) transceiver transmits and receives wireless signals and includes a second PLL that receives the timing signal from the crystal oscillator during the active mode. A first oscillator selectively generates a first clock signal during the low power mode. The first oscillator dissipates less power than the crystal oscillator.

[0009] In still other features, when the MAC device initiates the low power mode, at least one of the first voltage regulator, the RF transceiver, the crystal oscillator, the first PLL, and the second PLL are shut down.

[0010] In yet other features, the MAC device includes a counter. When the MAC device initiates the low power mode, the second voltage regulator

powers the first oscillator and the counter. When the counter reaches a predetermined count, the MAC device powers up at least two of the crystal oscillator, the first voltage regulator, the RF transceiver and the first and second PLL.

[0011] In still other features, the wireless Ethernet network device is operated in one of an infrastructure mode and an ad-hoc mode. The MAC device includes an external interface. When the MAC device receives a wake up signal from a host via the external interface, the MAC device powers up at least two of the crystal oscillator, the first voltage regulator, the RF transceiver and the first and second PLL.

[0012] In still other features, the crystal oscillator is an external crystal oscillator. Alternately, the crystal oscillator includes an external crystal and an integrated amplifier. The wireless Ethernet network device dissipates less than 2mW when in the low power mode.

[0013] In still other features, the MAC device includes transmit and receive state machines and a transmit buffer. The MAC device initiates the low power mode when the transmit buffer is empty and the transmit and receive state machines are idle.

[0014] In still other features, a processor calibrates the first oscillator using the timing signal from the crystal oscillator.

[0015] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating

the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0017] Figure 1 illustrates a wireless network that is configured in an infrastructure mode and that includes a mobile station and an access point according to the prior art;

[0018] Figure 2 illustrates a wireless network that is configured in an ad-hoc mode and that includes multiple mobile stations according to the prior art;

[0019] Figure 3 is a functional block diagram of a wireless network communications device that implements a power savings mode according to the present invention;

[0020] Figure 4 is a timing diagram that illustrates operating modes and supply voltage levels;

[0021] Figure 5 is a flowchart illustrating steps performed by the wireless network communications device to enter the power savings mode when configured in the infrastructure mode;

[0022] Figure 6 is a flowchart illustrating steps performed by the wireless network communications device to exit the power savings mode when configured in the infrastructure mode;

[0023] Figure 7 is a flowchart illustrating steps performed by the wireless network communications device to enter the power savings mode when configured in the ad-hoc mode; and

[0024] Figure 8 is a flowchart illustrating steps performed by the wireless network communications device to exit the power savings mode when configured in the ad-hoc mode.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the term device refers to an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, or other suitable components that provide the described functionality.

[0026] Referring to Figure 1, a first wireless network 28 is illustrated in an infrastructure mode as defined by IEEE 802.11 and other future wireless standards. The first wireless network 28 includes one or more mobile stations 30 and one or more access points (AP) 32. The mobile station 30 and the AP 32 transmit and receive wireless signals 34. The AP 32 is a node in a network 36. The network 36 may be a local area network (LAN), a wide area network (WAN), or another network configuration. The network 36 may include other nodes such

as a server 38 and may be connected to a distributed communications system 40 such as the Internet.

[0027] The mobile station 30 does not continuously transmit data to or receive data from the AP 32. Therefore, the mobile station 30 implements a power savings mode when the mobile station 30 and the AP 32 do not have data to exchange. Data commonly remains intact in a network for a predetermined amount of time before it is dropped. IEEE section 802.11 provides the opportunity for the mobile station 30 to inform the AP 32 when the mobile station 30 is entering a low power mode (and will not be capable of receiving data for a predetermined period of time). After notifying the AP, the mobile station transitions to the low power mode. During the low power period, the AP 32 buffers data that is intended to be transmitted to the mobile station 30. Following the low power period, the mobile station 30 powers up and receives beacon transmissions from the AP 32. If the beacon transmissions indicate that the AP 32 has data for the mobile station 30, the mobile station 30 remains active. Otherwise, the mobile station 30 enters the low power mode again.

[0028] Referring now to Figure 2, a second wireless network 42 operates in an ad-hoc mode as defined by IEEE section 802.11 and other future wireless standards. The second wireless network 42 includes multiple mobile stations 44-1, 44-2, and 44-3 that transmit and receive wireless signals 46. The mobile stations 44-1, 44-2, and 44-3 collectively form a LAN and communicate directly with each other. The mobile stations 44-1, 44-2, and 44-3 are not necessarily connected to another network. The mobile stations 44-1, 44-2, and

44-3 do not continuously transmit data to and receive data from each other. The mobile stations 44 implement a power savings mode when one of the mobile stations 44-1 does not have data to exchange with the other mobile stations 44-2 and 44-3.

[0029] IEEE section 802.11 does not require the mobile stations 44-1, 44-2, and 44-3 to buffer data as performed in the AP. The mobile station 44-1 informs the other mobile stations 44-2 and 44-3 that the mobile station 44-1 is entering the low power mode for the low power period. According to the present invention, the other mobile stations 44-2 and 44-3 preferably extend the life of data intended for the mobile station 44-1 for the predetermined period. Alternately, the other mobile stations retransmit data until the low power period expires. Following the low power period, the mobile station 44-1 detects whether the other mobile stations 44-2 and 44-3 have data for the mobile station 44-1 (to determine whether or not to execute the low power mode again).

[0030] Referring now to Figure 3, a wireless network communications device 48 in a mobile station operates in two power modes. In an active mode, the wireless network communications device 48 processes incoming and outgoing data. In the low power mode, the wireless network communications device 48 does not transmit or receive data. In one implementation, the wireless network communications device 48 includes an SOC circuit 50, an external radio frequency (RF) transceiver 52, and a crystal oscillator (XOSC) 54. The crystal oscillator 54 can be located externally or the amplifier portion of the crystal

oscillator 54 can be integrated with the SOC circuit 50 and the crystal portion of the crystal oscillator 54 can be located externally.

[0031] The RF transceiver 52 wirelessly transmits/receives data to/from an AP or another mobile station. The XOSC 54 provides a reference signal 56 to first and second phase-locked loops (PLL) 58 and 60. The first PLL 58 is located in the SOC circuit 50 and the second PLL 60 is located in the RF transceiver 52. The first and second PLL 58 and 60 generate clock signals that are based on the reference signal 56 from the XOSC 54. For example, the XOSC 54 may provide a reference signal at a frequency of 44 MHz, although other frequencies may be used.

[0032] In one implementation, the SOC circuit 50 includes a baseband processor (BBP) 62, a medium access control (MAC) device 64, and other SOC components 66. The BBP 62 includes a digital voltage regulator 68, an analog voltage regulator 70, and the first PLL 58. The digital and analog voltage regulators 68 and 70, respectively, supply regulated voltages to one or more components in the SOC circuit 50. For example, the digital voltage regulator 68 may operate at 1.5V and the analog voltage regulator 70 may operate at 2.5V. Those skilled in the art can appreciate that additional analog and/or digital voltage regulators and/or voltage regulators operating at other voltages may be employed. The first PLL 58 generates one or more clock signals 72 for the MAC device 64, one or more clock signals 74 for the other SOC components 66 and one or more clock signals for the BBP 62 based on the reference signal 56 from the XOSC 54.

[0033] The MAC device 64 transmits a transceiver mode signal 76 to the RF transceiver 52. The transceiver mode signal 76 instructs the RF transceiver 52 to operate in the active mode or the low power mode. The RF transceiver 52 transmits and receives RF signals during the active mode. The RF transceiver remains deactivated during the low power mode and does not transmit or receive RF signals. Preferably, the RF transceiver 52 is completely shut down for maximum power reduction. However, during the low power mode, the RF transceiver 52 may utilize a small amount of power to ensure a quick transition from the low power mode to the active mode.

[0034] The MAC device 64 also transmits a BBP mode signal 78 to the BBP 62. The BBP mode signal 78 instructs the BBP 62 to operate in the active mode or the low power mode. The other SOC components 66 include a host interface 80, a processor 82 and memory 83. The host interface 80 provides an interface such as peripheral component interconnect (PCI) interface or other suitable interfaces. The host interface may be connected to a host. The processor 82 may be an advanced RISC machine (ARM) processor and/or any other processor. The memory 83 stores data.

[0035] The MAC device 64 executes the low power mode when the wireless network communications device 48 and either an AP or another mobile station do not have data to exchange. Before executing the low power mode, the MAC device 64 also preferably ensures that the transmit buffer is empty, that the transmit and receive state machines are idle and that the wireless network communications device 48 is not currently in the process of receiving or

transmitting data. The duration that the wireless network communications device 48 operates in the low power mode varies. The start time is variable and the end time is fixed (in other words, the low power mode ends before the start of the next beacon). If the wireless network communications device 48 is not triggered during the low power mode, it returns to the active mode before the start of the next beacon. The XOSC 54 consumes a significant amount of power during the active mode. For example, the XOSC 54 may consume 10-12 mA of current. Therefore, the MAC device 64 deactivates the XOSC 54 during the low power mode.

[0036] The BBP 62 includes a low power oscillator 84 that provides a signal 86 to a counter 88 in the MAC device 64. For example, the low power oscillator 84 may be implemented either internally (as shown) or externally and may operate at a frequency of 100 kHz. The counter 88 determines the amount of time that the wireless network communications device 48 operates in the low power mode. The low power oscillator 84 is typically susceptible to performance deviations due to temperature variances. Therefore, before the wireless network communications device 48 enters the low power mode, the processor 82 may calibrate the low power oscillator 84 using the XOSC 54 to ensure that the low power oscillator 84 accurately tracks the desired low power time period. The calibration may be performed every time that the low power mode occurs, periodically, randomly, on an event basis or using any other criteria.

[0037] For example, the processor 82 may measure the difference between the frequency of the low power oscillator 84 and the frequency of the

XOSC 54. Based on the frequency difference, the processor 82 determines the number of times that the counter 88 must increment to equal a desired period. The XOSC 54 can also calibrate the low power oscillator 84 on a periodic basis.

[0038] The MAC device 64 includes an input/output (I/O) module 90, which may be located outside of the MAC in the SOC circuit 50. For example, the I/O module 90 may be a general purpose I/O module (GPIO). In the event that a mobile station requires the wireless network communications device 48 to return to the active mode, the mobile station triggers an I/O input 92. If the I/O input 92 is triggered during the low power mode, the wireless network communications device 48 returns to the active mode. Some host interfaces such as a compact flash card may not include a signal to trigger the I/O module. In that case, the processor 82 generates an interrupt when the wireless network communications device 48 returns to the active mode. The interrupt queries the host to determine whether the host has data to transmit.

[0039] The MAC device 64 executes the low power mode in an infrastructure network by first transmitting the low power period to the AP. In an ad-hoc network, the transmit beacon period is assumed. The low power period may specify a listen interval. The listen interval is equal to a full cycle of operation of the wireless network communications device 48 in the active and low power modes, as will be described in further detail below. Next, the processor 82 optionally calibrates the low power oscillator 84 using signals generated by the XOSC 54. The MAC device 64 instructs the BBP 62 and the RF transceiver 52 to enter the low power mode. The MAC device 64 disables

internal clocks in the SOC circuit 50 and then the PLL 58 and 60. The MAC device 64 disables the XOSC 54 and the voltage regulators 68 and 70 the XOSC 54 and the first PLL with a disable signal 94.

[0040] [0]Since the MAC device 64 disables the digital voltage regulator 68 during the low power mode, the BBP 62 includes a low power digital voltage regulator 98. The low power voltage regulator 98 dissipates less power than the other voltage regulators. For example, the voltage regulator 98 may operate at 1.3 V and with a lower current level than the other regulators. The low power voltage regulator 98 provides power for the low power oscillator 84 and the counter during the low power mode. [0]The low power voltage regulator 98 also supplies power to registers and memories in the SOC circuit 50 so that the state of the SOC circuits 50 is retained, which is important for fast wake up time. The MAC device also includes transmit and receive state machines 99 and a transmit buffer 100.

[0041] During the low power mode, the I/O module 90 monitors the I/O input 92. If the I/O input 92 is not triggered during the low power mode, the wireless network communications device 48 returns to the high power mode after the counter 88 reaches the end of the low power period. In order to return to the active mode, the MAC device 64 enables the voltage regulators 68 and 70 and the XOSC 54, respectively. The MAC device 64 activates the first PLL 58. The MAC device next enables the internal clocks 72 and 74. Finally, the MAC device 64 instructs the BBP 62 and the RF transceiver 52 to operate in the active mode.

[0042] In the infrastructure network, the AP periodically broadcasts beacon transmissions. The beacon transmissions include a traffic map that indicates whether the AP has buffered data that requires transmission to a mobile station. When the wireless network communications device 48 returns to the active mode, the processor 82 examines the traffic map in one of the beacon transmissions. If the traffic map indicates that an AP does not have data to transmit to the wireless network communications device 48, the MAC device 64 executes the low power mode again. The processor also checks with the host system to see if the host has any data to transmit.

[0043] In the ad hoc mode, there is an Announcement Traffic Indication Message (ATIM) period during which mobile stations send directed ATIM messages. The mobile station wakes up prior to the ATIM period. If an ATIM message is directed to the mobile station during the ATIM period, the mobile station remains in the active mode. Otherwise the mobile station transitions back to the low power mode.

[0044] Referring now to Figure 4, an exemplary timing diagram 106 according to the present invention is illustrated. A chipset mode signal 108 identifies the active mode and the low power mode. A listen interval 110 is equal to a full cycle (high and low power modes) of the wireless network communications device 48. A supply voltage signal 112 indicates the voltage level that is supplied by either the digital voltage regulator 68 or the low power digital voltage regulator 98. The supply voltage signal 112 illustrates the supply voltage fluctuation between 1.3 V to 1.5 V prior to the wireless network

communications device 48 returning to the normal mode. As can be appreciated, other higher and/or lower voltage levels may be used (such as but not limited to 1.1V and 1.3 V). This ensures that the digital voltage regulator 68 supplies a sufficient amount of power to devices such as the BBP 62 when the devices return from the low power mode. Additionally, the supply voltage decreases from 1.5 V to 1.3 V shortly after the wireless network communications device 48 enters the low power mode. This ensures that the SOC circuit 50 receives sufficient power and avoids overloading before devices such as the BBP 62 are completely deactivated.

[0045] A beacon transmission signal 114 illustrates an exemplary beacon transmission pattern from the AP. The listen interval 110 is typically measured by the number of beacons 116. The wireless network communications device 48 informs the AP that the wireless network communications device 48 will be in the low power mode for a predetermined number of beacons 116. For example, beacon transmissions may take place every 100 ms. Therefore, the listen interval 110 will typically range from 100 ms to a few seconds. Preferably, the wireless network communications device 48 returns to the active mode just prior to a beacon transmission. Therefore, the wireless network communications device 48 does not have to operate in the active mode for a long time while an AP has no data to transmit. For example, the wireless network communications device 48 may operate in the active mode for 20 ms, or approximately 1% to 10% of the listen interval 110 when the AP does not have data to transmit.

[0046] The wireless network communications device 48 preferably transmits the listen interval period to the AP when the wireless network communications device 48 initially associates with the AP rather than each time that the wireless network communications device 48 enters the low power mode.

[0047] Referring now to Figure 5, an infrastructure mode shutdown algorithm 124 begins in step 126. In step 128, the wireless network communications device determines whether the host system has data to transmit or whether data is being received. If true, control returns to step 126. If false, control proceeds to step 130. In step 130, the wireless network communications device 48 executes a power save frame exchange, which indicates that the wireless network communications device is entering a low power mode. In step 132, the processor 82 optionally calibrates the low power oscillator 84 using signals generated by the XOSC 54. In step 134, the BBP and the RF transceiver are transitioned to the low power mode or state. In step 136, the internal clocks are disabled and the PLLs, the XOSC and the voltage regulators are shut down. Control ends in step 138.

[0048] Referring now to Figure 6, an infrastructure mode low power algorithm 140 begins in step 142. In step 143, control determines whether the counter is up or an I/O event occurs. If true, control continues with step 144 where the wireless network communications device exits the power saving mode by enabling voltage regulators, the XOSC, the PLLs and the internal clocks. In step 146, the wireless network communications device determines whether the host system has data to transmit. If not, the wireless network communications

device determines whether the access point has data to transmit in step 148. If not, the low frequency oscillator is optionally calibrated in step 150. In step 152, the RF transceiver and the BBP are transitioned to the low power mode or state. In step 154, the internal clocks are disabled and the PLLs, the XOSC and the voltage regulators are shut down. In step 155, control ends.

[0049] If either step 146 or 148 are true, the wireless network communications device enters the normal operating mode in step 156. The wireless network communications device executes power save frame exchange in step 158 and then continues with step 150, as described above.

[0050] Referring now to Figure 7, an ad-hoc mode shutdown algorithm 160 begins in step 162. In step 164, control determines whether the mobile station has data to transmit or whether data is being received. If true, control returns to step 162. If false, control proceeds to step 166. In step 166, the wireless network communications device 48 executes a power save frame exchange. In step 168, the processor 82 optionally calibrates the low power oscillator 84 using signals generated by the XOSC 54. In step 134, the RF transceiver and the BBP are transitioned to the low power state or mode. In step 172, the internal clocks are disabled and the PLLs, the XOSC and the voltage regulators are shut down. Control ends in step 174.

[0051] Referring now to FIG. 8, an ad-hoc mode low power algorithm 180 begins in step 182. In step 183, control determines whether the counter is up or an I/O event occurs. If true, control continues with step 184 where the wireless network communications device exits the power saving mode by

enabling the voltage regulators, the XOSC, the PLLs and the internal clocks. In step 186, the wireless network communications device determines whether the mobile station has data to transmit. If not, the wireless network communications device determines whether a directed Announcement Traffic Indication Message (ATIM) or multicast (MC) ATIM management signal is received during the ATIM period in step 188. If not, the low frequency oscillator is calibrated in step 190. In step 192, the PHY (the RF transceiver and the BBP) are transitioned to the low power mode. In step 194, the clocks are disabled and the PLL, XOSC and voltage regulators are shut down. In step 195, control ends.

[0052] If either step 186 or 188 are true, the wireless network communications device enters the normal operating mode in step 196. The wireless network communications device executes a power save frame exchange in step 198 and then continues with step 190, as described above.

[0053] The low power mode according to the present invention reduces power consumption in communications devices. In one implementation, power consumption was approximately 325mA during the transmit mode and 180mA during the receive mode. Current consumption was less than approximately 2mA and power consumption was less than 3mW during the low power mode.

[0054] As can be appreciated, the relative locations of the PLLs, the voltage regulators, the counter, the oscillators and other components of the wireless network communications device can be altered from that shown in the FIGs. without departing from the spirit of the invention. In addition, while the wireless communications device was implemented using an SOC circuit, skilled

artisans will appreciate that the wireless communications device can be implemented in any suitable manner. While the present invention was described in conjunction with IEEE section 802.11, the present invention applies to any wireless network device. The low power oscillator can be operated during the active mode so that the calibration can be performed. Likewise, the lower power voltage regulator can also be powered during the active mode If desired.

[0055] Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, specification, and the following claims.